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Bilal Mirza and Adam Szirmai

United Nations University - Maastricht Economic and social Research and training centre on Innovation and Technology
Keizer Karelplein 19, 6211 TC Maastricht, The Netherlands
Tel: (31) (43) 388 4400, Fax: (31) (43) 388 4499, e-mail: info@merit.unu.edu, URL: http://www.merit.unu.edu

Towards a New Measurement of Energy Poverty:

A Cross-Community Analysis of Rural Pakistan

Bilal Mirza* and Adam Szirmai
UNU-MERIT

Abstract:

Most rural households in Pakistan remain in a state of energy poverty. They use a variety of non-conventional energy sources, including traditional biomass (firewood, animal and plant waste), kerosene and even LPG. A specially designed Energy Poverty Survey (EPS), carried out in rural Pakistan from December 2008 till January 2009, showed that rural households use different combinations of energy sources (the energy mix). This paper analyses the characteristics and consequences of the different energy mixes, used by richer and poorer rural households. Using data from the EPS, we develop a composite index to measure the degree of *Energy Poverty* among rural households. This index takes into account the inconvenience for the household associated with the use of different sources of energy, as well as its energy shortfall and takes household size into account. In our results, we found that 23.1% of rural households experience high degrees of energy inconveniences, spending ample amount of their time and effort in collecting or buying different energy sources. Next, using the standard conversion units to convert different energy sources into kilowatt hours, we found that 96.6% rural households experience severe energy shortfalls. Our new and inclusive measure of energy poverty which combines the energy inconveniences and the energy shortfalls, reveals that 91.7% of all rural households in Punjab province of Pakistan are in the state of severe energy poverty.

Keywords: energy access; energy poverty measurement; energy indicators; energy inconvenience index; energy poverty index

JEL Codes: I32, O13, Q01

*** Corresponding author: Bilal Mirza, UNU-MERIT, Keizer Karelplein 19, 6211 TC, Maastricht, the Netherlands,**

Email: mirza@merit.unu.edu

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1. Introduction

Rural households without access to conventional energy sources like electricity and natural gas, use combinations of different energy sources to meet their household energy needs. These combinations are often referred to as the energy mix. Different factors like household income, the availability of energy sources or the main occupation of the household members come into play to determine the specific energy mix of the household. Households try to choose an energy mix which optimizes all the relevant factors associated with the energy sources in the particular energy mix used by a household.

The use of indicators is widespread in development research and practice. However, despite the important contributions in the energy and development literature, we still lack a universally accepted standard measure to determine the degree of energy poverty in rural households. Much of the research on energy poverty has focused on rural household energy expenditures, analysing the share of energy expenditure in household income and its implications for household welfare (see Baxter et al., 1986; Dendukuri and Mittal, 1993; Bailis and Cutler, 2004; Lara and Andrade, 2009; Reddy and Srinivas, 2009). In the earlier work of Pokharel (2006) and DFID, energy poverty is defined in terms of shortfalls in energy consumption (in Tonne of Oil Equivalent) relative to some threshold level or energy expenditures as percentage of household expenditures, respectively. Similarly, Pachauri et al. (2004) have proposed a two-dimensional energy based poverty measure, which takes into account useful energy used by rural and urban households with respect to their access to biomass, kerosene and LPG. In our view, despite important contributions to our understanding of this complex phenomenon, the literature still neglects many of the physical, social, and economic aspects which are highly specific to access for each energy source and to respective household energy needs.

One of the major challenges in measuring energy poverty is the lack of data on rural energy access. Until now, there is a dearth of data on rural households not only with regard to energy but also on income, education, health etc. Furthermore, the complexities involved in energy access for rural households are even difficult to track for research purposes. From existing research on rural energy access, we already know that rural households, that do not use conventional energy sources like electricity and natural gas, can be termed energy poor, as energy sources like traditional biomass, kerosene and LPG sources are not enough to ensure sustainable, reliable and continuous energy supply. As a step forward in the measurement of energy poverty, we propose a measure which could allow us to quantify the degree of energy poverty among rural households, using traditional biomass, kerosene and LPG.

For this purpose, we have developed an Energy Poverty Survey (EPS). In the EPS, we investigated the factors which have a decisive impact on the welfare of rural households when they make choices concerning energy sources and their energy mix. For traditional biomass, which includes firewood (bought and collected), animal and plant waste, we found a number of factors which might have impact on rural energy access for households, which will be discussed later in the paper.

The structure of the paper is as follows. In section 2, we describe the process of data collection and our survey sample characteristics. In section 3, we briefly discuss the different types of energy mix used by the households in our sample, as well as some typical characteristics of rural energy markets. In section 4, we discuss the methodology and components of our energy poverty indices. In section 5, we present the results of the application of the indexes developed in section 3. Section 6 concludes.

2. Data Collection

We conducted our own survey in rural communities in Pakistan. Using stratified random sampling at village[1] or community[2] level and random sampling at household[3] level, we included 27 rural communities, all of them without access to natural gas, but with or without electricity. The main reason for such stratification is that households only use variety of traditional energy sources in the absence of natural gas. At the first level of stratification, we selected rural communities which matched our criteria, namely, communities with or without electricity but without access to natural gas. At the second level of sampling, i.e., after selecting the rural communities matching our criteria, we drew a random sample of households to ensure that households with different economic characteristics were represented in the sample.

As shown in table 1, our sample covered 11 major districts of Punjab province – the most populous province of Pakistan. According to the 1998 census, out of a total rural population of 89 million, 51 million (57%) resides in Punjab province. Also, 70 percent of the Punjab population is rural and is involved in agriculture.

[1] Due to relatively higher population differences between urban and rural, non-availability of infrastructure, and geographical, social and economic variations in rural areas of Pakistan, we defined a village as a cluster of at most 1500 households, living in a particular locality.
[2] The term village and community is used interchangeably in the entire text.
[3] In our survey, we defined a household as a dwelling or a residential unit where at least 2 members reside together and share resources.

Table 1: EPS Sample Characteristics

Province	***Punjab***	***Household Members***	
Districts	**11**	2 to 5	**169 (26%)**
Rural Communities	**27**	5 to 10	**388 (60%)**
Communities with Electricity but no Gas	**19**	11 to 15	**66 (10%)**
Communities without Electricity and Gas	**6**	15 to 20	**12 (2%)**
Solar Communities without Electricity and Gas	**2**	20 +	**5 (1%)**
Gender		**Community Prosperity Level**	
Male	**599 (93.6%)**	Very Poor	**11**
Female	**41 (6.4%)**	Poor	**11**
Age Groups		Neither Poor nor Rich	**2**
Below 18 Years	**4 (0.6%)**	Rich	**0**
18yrs to 30yrs	**135 (21.1%)**	Very Rich	**0**
30yrs to 45yrs	**268 (41.9%)**	Not known	**3**
45yrs to 60yrs	**164 (25.6%)**		
60+	**69 (10.8%)**		

Source: Energy Poverty Survey

Out of total 27 rural communities from 11 major districts of Punjab, 19 rural communities were with electricity but no natural gas, 6 were without electricity as well as natural gas, whereas 2 of them were villages with access to solar energy, but without electricity and natural gas. The gender bias in our sample is clearly in favour of males due to social limitations to female participation, which make it difficult for them to interact with strangers. Despite this, we noticed considerable differences between male and female respondents and a relatively higher degree of awareness among female respondents regarding household energy problems, compared to our male respondents.

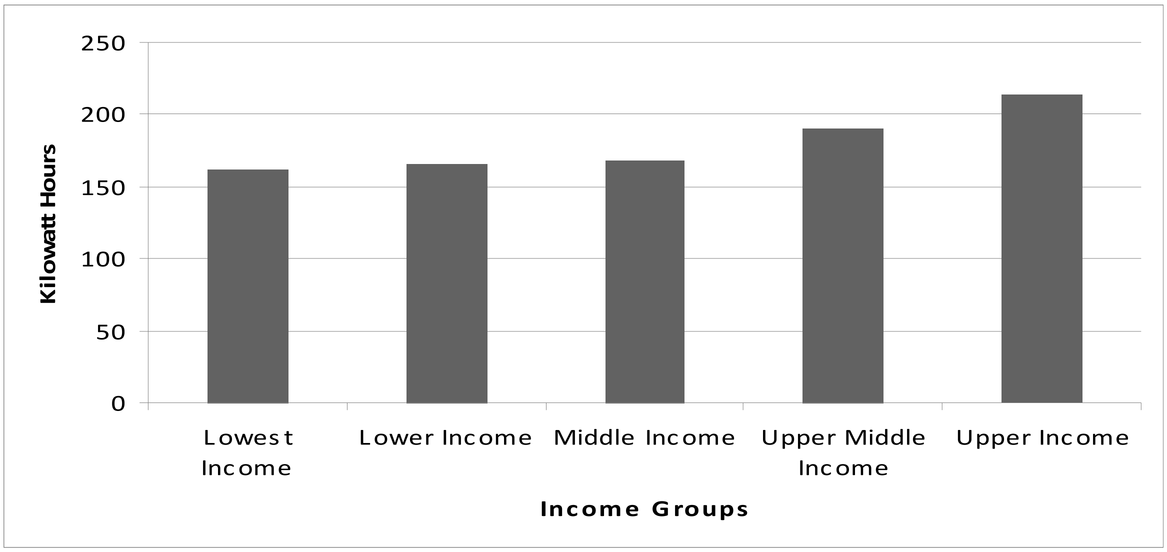
3. Household Income and Energy Use

Figure 1 shows a positive relationship between household income and energy consumption (in kilowatt hours). Households tend to consume more energy as they earn more. Kilowatt hours consumed per household are computed by summing the standard energy content of all energy sources used by a household (See Annex 1: Energy Source Conversions). At first sight the average energy consumption per capita using traditional energy sources might seem higher than that of households which have access to electricity and natural gas. This is misleading due to the fact that traditional biomass like firewood, animal and plant waste have lower energy efficiency. Most of the energy embodied in the source is wasted due to inefficient cooking appliances in rural households.

Several studies have pointed to the phenomenon of an energy ladder among rural households, whereby households tend to shift to better energy sources with higher efficiencies as their incomes increase. Household income is one of the most important determinants of the energy mix. Previous studies on energy and income relationship found that as the household income increases, households tend to shift from inconvenient and inefficient energy sources to more modern, convenient and efficient energy sources (see Leach, 1987, 1988, 1992; Davis, 1995; Karekazi, 2002). However other studies have also challenged the notion of any possible linear and unidirectional relationship between income and energy sources. Instead, these studies found that even with an increase in household incomes, rural households continue to make use of many inconvenient and inefficient energy sources. However their energy mix does tend to include more modern and convenient energy sources like liquid petroleum gas, compared to poorer households (Hosier and Dowd, 1987; Chambwera and Folmer, 2007; Horst and Hovorka, 2008).

Figure 1: Average Energy Consumption, by income group

(Kilowatt hours per Capita per Month)



* Kilowatt Hours are not controlled for useful energy content due to unknown useful energy percentage for each energy source.
Lowest Income Group = 1-.3000 Rupees (Rs; Lower Income Group = Rs. 3001-5000; Middle Income Group = Rs. 5001-8000; Upper Middle Income Group = Rs. 8001-12000; Upper Income Group = Rs. 12001 and above
Source: Energy Poverty Survey.

3.1 Types of Energy Mixes in Rural Punjab

Data from the EPS revealed that rural households use a variety of energy sources to meet their energy needs, resulting in different 'energy mixes'. We define the concept of energy mix as the proportion of different energy sources used by households to meet their energy needs. Table 2 provides a comprehensive overview of energy mixes found in rural households. In total six different energy sources are used: Animal waste, Electricity, Firewood bought, Firewood collected, Kerosene and Liquid petroleum gas. 57 different combinations of energy sources are identified (The exact proportions of sources use in each combination will of course vary from household to household).

Table 2: Type and Proportion of Energy Mixes in Rural Communities

Number of Different Energy Mixes	*Type of Energy Mixes*	*Number of Households Using*	*% of households*	*Fb*	*Fc*	*A*	*P*	*K*	*L*	*E*	*Number of Energy Sources*
				Energy Mix (in percentages)							
1	**E**	2	0.31							100.0	1
2	**Fb**	1	0.15	100.0							1
3	**Fc**	2	0.31		100.0						1
4	**K**	1	0.15					100.0			1
5	**AE**	9	1.40			74.5				25.5	2
6	**FbA**	1	0.15	36.9		63.1					2
7	**FbE**	29	4.53	69.9						30.1	2
8	**FbK**	3	0.46	96.4				3.6			2
9	**FcE**	11	1.71		53.1					46.9	2
10	**FcK**	51	7.96		87.4			12.6			2
11	**FcP**	1	0.15		87.2		12.8				2
12	**LE**	26	4.06						40.5	59.5	2
13	**PE**	1	0.15				20.5			79.5	2
14	**PK**	18	2.81				50.4	49.6			2
15	**ALE**	3	0.46			81.3			4.6	14.1	3
16	**APK**	2	0.31			94.0	1.1	4.8			3
17	**FbAE**	117	18.28	42.6		40.6				16.8	3
18	**FbAK**	6	0.93	44.2		54.3		1.5			3
19	**FbFcE**	5	0.78	59.5	19.8					20.6	3
20	**FbFcK**	2	0.31	70.2	24.8			5.0			3
21	**FbKE**	11	1.71	71.8				5.1		23.1	3
22	**FbLE**	43	6.71	59.2					15.1	25.7	3
23	**FbPE**	2	0.31	60.3			12.5			27.2	3
24	**FbPK**	14	2.18	81.9			13.1	5.1			3
25	**FcAE**	35	5.46		8.4	73.4				18.2	3
26	**FcAK**	12	1.87		23.9	72.5		3.5			3
27	**FcKE**	10	1.56		32.5			9.6		57.9	3
28	**FcLE**	16	2.5		14.7				31.6	53.7	3
29	**FcPE**	1	0.15		76.9		5.7			17.5	3
30	**FcPK**	33	5.15		51.6		21.8	26.6			3
31	**KLE**	2	0.31					3.9	35.1	61.0	3
32	**AKLE**	1	0.15			69.6		0.3	10.9	19.3	4
33	**FbAKE**	9	1.40	28.5		47.2		2.0		22.3	4
34	**FbALE**	53	8.28	39.6		38.7			8.1	13.6	4
35	**FbAPE**	1	0.15	51.7		20.5	1.9			26.0	4
36	**FbAPK**	4	0.62	45.8		48.0	2.7	3.5			4
37	**FbFcAE**	6	0.93	33.5	2.6	45.2				18.7	4
38	**FbFcAK**	1	0.15	16.1	0.5	82.3		1.1			4
39	**FbFcKE**	1	0.15	47.3	15.8			2.4		34.6	4
40	**FbFcPK**	3	0.46	69.6	10.2		5.3	14.9			4
41	**FbKLE**	6	0.93	53.2				3.0	14.8	29.0	4
42	**FcAKE**	6	0.93		19.5	62.4		2.7		15.4	4
43	**FcAKL**	1	0.15		17.6	80.2		1.5	0.7		4
44	**FcALE**	22	3.43		5.7	66.6			7.7	20.1	4
45	**FcAPK**	16	2.5		8.0	87.1	2.5	2.4			4
46	**FcKLE**	6	0.93		10.9			9.1	31.3	48.6	4
47	**FbAKLE**	6	0.93	25.0		53.8		1.2	4.6	15.4	5
48	**FbFcAKE**	4	0.62	19.2	12.9	59.3		1.7		6.9	5
49	**FbFcALE**	4	0.62	28.5	8.1	43.1			5.7	14.6	5
50	**FbFcAPK**	3	0.46	15.8	2.8	74.7	3.0	3.6			5
51	**FbFcKLE**	2	0.31	69.5	11.1			1.2	5.8	12.4	5
52	**FbPKLE**	1	0.15	52.0			11.5	5.9	16.3	14.3	5
53	**FcAKLE**	7	1.09		12.7	69.9		1.7	6.1	9.6	5
54	**FbAPKLE**	2	0.31	34.8		36.4	1.1	1.2	5.4	21.2	6
55	**FbFcAKLE**	2	0.31	33.9	2.6	22.9		2.7	10.8	27.2	6
56	**FbFcAPLE**	1	0.15	26.0	9.8	53.3	1.5		1.5	8.0	6
57	**FcAPKLE**	2	0.31		27.6	51.8	1.1	1.9	3.4	14.2	6
	Total	640	100								

Note: A= Animal waste, E= Electricity, Fb= Firewood bought, Fc= Firewood collected, K= Kerosene, L= Liquid petroleum gas.
Source: Energy Poverty Survey

The energy mixes used by households range from a minimum of 1 energy source to a maximum of 6 different energy sources. In our sample of 640 households, only 6 households use a single energy source. Firewood, both collected and bought, is the most common energy source in use. It is included in 47 of the energy mixes. Electricity is included in 37 of the energy mixes, kerosene in 31 energy mixes.

3.2 How rural energy markets function

Rural energy markets function differently from urban energy markets. There are four main reasons for this. Firstly, due to lack of infrastructure for the supply of electricity and natural gas, rural households mostly have to rely on traditional biomass, kerosene and sometimes liquid petroleum gas. In urban areas, the infrastructure for electricity and natural gas is available, so that urban households have convenient access to these modern energy sources. Therefore, urban household can ignore all other energy sources entirely.

Secondly, rural households have a range of energy choices, among which they opt for those which provide them an energy mix that best corresponds to their financial means and energy requirements. Their choices depend on factors such as convenience of access, proximity, availability including seasonal availability, and price.

Thirdly, the rural energy market structure also plays a very important role. With market structure, we specifically refer to the nature of supply in the rural communities, which will differ from energy source to energy source. Energy suppliers will tend to locate in those communities where the majority of the population demands a particular energy source. For instance, households in rural communities where very few households can afford modern energy sources like LPG, have to buy it from distribution agencies or wholesale sellers located in nearby towns or cities rather than from suppliers in their own community. On the other hand, in the case of traditional biomass, the sellers are clustered in and around the rural community, providing far more convenient and affordable access to rural households using firewood. Thus, this supply structure creates a very imperfect market for energy access.

Last but not the least, a hallmark of rural energy markets is that households use informal market mechanisms to access traditional biomass. For instance, households which have their own land in the nearby community usually have seasonal access to plant waste which can be used as an energy source. Households with excessive plant waste can either share it with other households for free or sell it to households without land. This depends on the type, usability and demand of a plant waste in a specific season. In our sample, rural households reported that plant wastes of cotton after its harvest are one of the most demanded energy source due to its relatively higher energy efficiency. Other plant wastes used are those of sunflower, wheat, rice and corn. To sell their products (plant wastes) in the market, landlords use two different modes of pricing, i.e., based on weight or based on the planted area. Under the former type of pricing, landlords sell plant wastes in units of 40 kilograms, locally known as *mann*.

As regards animal waste, households with livestock ownership also follow a similar kind of informal market interaction with other households, selling or giving away excessive animal waste. From interviews with rural households using animal waste, we found that animal waste is sold through networks among rural households in a specific community. Households without livestock ownership, that want to use animal waste as an energy source, use two modes of access to animal waste, depending on their social status (or income category). Higher income group households without livestock ownership prefer to buy animal waste from rural households with livestock ownership, whereas in most cases, lower income group households have '*access in kind*' from higher income group households with livestock ownership.. In such types of access, female members of lower income group household process the animal dung, which involves the cleaning of cattle sheds and making the animal waste suitable for use as an energy source. In that way, the household with livestock gets complementary services from its poor and needy neighbours, in exchange for animal waste. In almost all cases, we found that households with livestock ownership are the prime users of animal waste as an energy source. They only choose for exchanges with poor households, when the quantity of animal waste is higher than what they need for manure and energy.

4. A New Index of Energy Poverty

In our approach, energy poverty is seen as determined by two elements: the excess inconvenience associated with the energy mix used by rural households and a lack of sufficient energy to meet basic household needs, the energy shortfall. The novel aspect of our new indicator is that it combines existing measures of energy shortfall with measures of inconvenience associated with the use of traditional energy sources. In the following paragraph steps 1-5 focus on the measurement of inconvenience, step 6 provides a measure of energy shortfall. In step 7, the two indicators are combined into our new indicator for energy poverty.

Energy Inconvenience

The use of traditional energy sources by rural households always comes with associated inconveniences, which are not associated with modern sources such as electricity and gas. From the collection of firewood, to the buying of LPG, rural households are required to make extra-ordinary efforts to meet their domestic energy needs. Households with better energy access in terms of kilowatt hours (kwh) are normally those who suffer highest degrees of inconvenience. In this context, we define the energy inconveniences for a household as the degree of physical difficulties or inconveniences involved in acquiring and using a particular energy source to meet household energy needs.

To measure energy inconvenience, we identified the following indicators which are relevant for energy access by rural households:

1. Frequency of buying or collecting a source of energy
2. Distance from household travelled
3. Means of transport used
4. Household member's involvement in energy acquisition

5. Time spent on energy collection per week
6. Household health
7. Children's involvement in energy collection

For all 6 different types of energy sources given in table 2, we identified seven dimensions of inconvenience. Five of these indicators – numbers 2, 3, 4, 5 and 7 above - are common for all energy sources. In the case of traditional biomass, which includes firewood (collected and bought), animal and plant waste, all 7 indicators mentioned above are relevant. In the case of kerosene[4], 6 indicators are used, including 5 common indicators and number 6 (household health), whereas for LPG, all common indicators are used.

4.1 The computation of the energy poverty index

The computation of the energy poverty index involves the following steps.

Step 1: Computing the Inconvenience Index for Each Inconvenience Indicator

In step 1 we make use of the survey responses to the questions about each of the dimensions of inconvenience.

Accounting for household size

Before continuing we first need to take household size into account. Some of the indicators mentioned above are highly dependent on the number of household members in a given household) and may be affected by the changes in household composition. To overcome that, we have normalized three of the inconvenience indicators by household size. The normalised indicators are: frequency of buying or collecting, household involvement and time spent on energy collection per week. As household size increases, the household will have to spend more time to collect a larger amount of firewood or might have to involve higher number of household members (household involvement indicator) in collecting or buying a specific energy source. Therefore, we have divided the response scores on these indicators by the number of household members to control for the household size effect. The other indicators of inconvenience such as health or distance are not affected by household size.

Using the methodology of the Human Development Index (HDI) (Haq, 1990), the general formula for computing the index is as following

$$X_{hij} = \frac{R_{hij} - R_{ij(\min)}}{R_{ij(\max)} - R_{ij(\min)}} \qquad \textbf{1}$$

[4] The questionnaire did not include a question on the frequency of buying kerosene, but from our informal discussion with rural households, we know that in general it is very infrequent.

Where

R is the response score to a question about energy inconvenience
h represents the household
i represents the type of inconvenience indicator
j represents the type of energy source,
min and max represent the minimum and maximum scores for indictor *i* and energy source *j*

Equation 1 provides a measure of a given kind of inconvenience associated with a given energy source used by a household.

Step 2: Computing the Energy Inconvenience Index (EII) at Energy Source level

After computing an index for each inconvenience indicator associated with a given energy source in step 1, we compute the aggregate energy inconvenience for each energy source *j* used by a given household *h*, as the unweighted average of the separate inconvenience indexes, as following:

$$EII_{hj} = \frac{\sum_{i=1}^{n} X_{hij}}{N_{ij}} \qquad \mathbf{2}$$

Where,

EII_{hj} is the *Energy Inconvenience Index* for a given energy source *j* in household *h*

$\sum_{i=1}^{n} X_{hij}$ is the sum of inconvenience indexes *i* for a given energy source *j* used by household *h*.

N is the number of inconvenience indicators relevant for a given energy source (e.g. for traditional biomass *N*=7, for kerosene *N*=6 and for LPG *N*=5).

The reason for using the average of the inconvenience indexes is that high inconvenience in one type of indicator may be compensated by low inconvenience on another indicator.

Step 3: Computing the Total Energy Inconvenience Index (TEI) for each household

In step 3, we compute the household inconvenience index TEI_h by aggregating the inconvenience indexes for all energy sources *j* used by a single household *h,* weighting them by the share of an energy source (in kilowatt hours) in total household energy use, as follows:

$$TEI_h = \sum_{j=1}^{6} \frac{KW_{hj}}{\sum KW_{hj}} (EII_{hj}) \qquad \textbf{3}$$

Where:

TEI_h represents the Total Energy Inconvenience index for household h, given its specific energy mix.

$\frac{KW_{hj}}{\sum KW_{hj}}$ gives us the share of energy in kilowatt hours from a given energy source j in household's total energy use in kilowatt hours.

From our energy poverty survey, we have information on the amounts of different energy sources used by the households. We have used the standard conversion factors to convert quantities of energy sources used into kilowatt hours (see Annex 1: Energy Source Conversion factors).

Step 4: Defining the Total Energy Inconvenience Threshold (TEIT)

In order to analyse energy poverty, we have to define a threshold level of inconvenience – the total energy inconvenience threshold TEIT - beyond which a household will be defined as energy poor in terms of the high inconvenience associated with its pattern of energy use.

The threshold level for inconvenience is set at 30% above the average value of total energy inconvenience (equation 3). The mean value of the *Total Energy Inconvenience (TEI)* in the sample is **0.249**. The *total energy inconvenience threshold*, $TEIT_h$ is then calculated as

$$TEIT_h = 0.249 * 1.3 = 0.323 \qquad \textbf{4}$$

The value of 0.323 gives us the threshold level of energy inconvenience. Below this level the inconvenience experienced by rural households is considered to be acceptable. Above the threshold level, the degree inconvenience indicates that the household suffers from energy poverty.[5]

[5] The threshold level indicates that poverty is seen as a relative concept. In a comparable fashion households that are earning less than 30% of mean income are often defined as poor. The cut-off value itself remains somewhat arbitrary. As the original scores are available, researchers can experiment with different threshold levels that are consistent with theories of poverty and relative deprivation.

Step 5: Computing the Energy Inconvenience Excess (EIE) at household level

In this step, the total energy inconvenience scores are converted into percentages relative to the threshold level, so that a meaningful interpretation can be given to the index values. The degree of inconvenience beyond the threshold level (TEIT) is referred to as the Energy Inconvenience Excess (EIE), which is computed as following:

$$EIE_h = \left(\left(TEIT_h - TEI_h\right) \big/ TEIT_h \right) \times 100 \qquad 5$$

Where

EIE_h refers to the Inconvenience Excess for household *h.*

EIE_h is expressed in percentages. A negative sign indicates that rural households are in the state of excess of inconvenience whereas a positive sign indicates that households are in the state of 'convenience'.

Step 6: Calculating the Energy Shortfall (ES) for households

Step six focuses on the second dimension of energy poverty, namely, Energy Shortfall – a situation when households are not having sufficient energy to meet basic household needs.

E*nergy shortfall* (*ES*) is calculated as follows

$$ES_h = \left(\left(AEC_h - TER\right) \big/ TER \right) \times 100 \qquad 6$$

Where :

ES_h represents the *energy shortfall* of household h

AEC_h represents the *actual energy consumption per capita* (in kilowatt hours), using type of energy sources *j* in a given household *h.*

TER represents the per capita *threshold energy requirements* (in kilowatt hours)

The *AEC* per capita is calculated by converting all the energy sources into kilowatt hours on the basis of the quantities of energy sources used by a single household As in step 3, we have used standard conversion factors to convert quantities of energy sources used into kilowatt hours (see Annex 1: Energy Source Conversion Factors).

The *TER* is a threshold value in kilowatt hours below which an individual has insufficient energy and is considered to be energy poor. The TER is derived from the secondary literature. It can be calculated on the basis of the TOE (tonne of oil Equivalent) per annum per capita required to attain 0.8 level on HDI (Human Development Index) (see Pokharel 2006). However, a threshold level of 1 TOE derived from HDI is characteristic for advanced economies. It is less relevant for rural communities of developing countries such as Pakistan. For that reason, we have adjusted the energy requirement level to 0.7 TOE.

By converting 0.7 TOE into *kilowatt hours* (kwh) and then dividing it by 52 for weekly requirements, we get a threshold value of 156.55 kwh per week per capita. Note that our shortfall measure is also on a per capita basis, so that we can compare households of different sizes.[6] To make the energy inconvenience index and the energy shortfall index comparable, so that same sign should indicate energy poverty, we subtracted the *TER* from the AEC_h instead of subtracting the AEC_h from the *TER*. Thus, a household energy shortfall is represented by negative values.

Step 7: Computing the Energy Poverty Index (EPI):

After computing the degree of energy inconveniences expressed by the *Energy Inconvenience Excess,* EIE_h and the degree of energy shortfall by *Energy Shortfall,* ES_h, the final step is to combine the two indicators into one, which gives us the *Energy Poverty Index* (*EPI*) for a given household.

EPI is calculated as the unweighted average of EIE_h *and* ES_h, as follows

$$EPI_h = \frac{1}{2}\left(EIE_h + ES_h\right) \qquad \mathbf{7}$$

Equation 7 gives us the degree of energy poverty in a household, on a per capita basis. Negative values indicate that a household is energy poor, positive values indicate that a household is not energy poor.

4.2 Measuring the degree of Energy Inconvenience

In this paragraph we discuss the ways in which various dimensions of inconvenience discussed in step 1 have been operationalised in the survey.

4.2.1 Buying or Collection Frequency:

The frequency of buying or collecting refers to the number of times households buy or collect a given energy source in one week. In our survey, we differentiated between the buying and collection of energy sources such as firewood. Rural households were asked specifically to differentiate not only between the buying and the collection of energy sources, but also to specify whether households combine buying and collection of their energy sources.

[6] In this survey we only had data on household size, not on household composition. A further elaboration of the method would be to use household equivalence scales to compare the energy shortfall of households.

We consider the frequency of buying or collection as a very important factor in energy access. Making such a differentiation between buying and collection of energy sources helps us understand the household situation. We found that collected firewood is always preferred by poor households in rural communities due to its free availability. As shown in table 3, scores ranging from 1 to 10 are given to responses based on the relative inconvenience levels. In the case of buying or collection frequency, we argue that buying or collecting an energy source 'once a year' is more convenient than buying or collecting an energy source every month. Hence, a score of 1 is assigned to the 'once a year' category, which represent the least inconvenience, whereas 'every month' category corresponds to score of 4, indicating its higher inconvenience.

Table 3: Inconvenience Scores for Buying or Collection Frequency

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Buying or Collection Frequency (uncontrolled)	Once a year	Twice a year	Every 3 months	Every month	Twice a month	Once a week	Twice a week	Thrice a week	Every other day	Every day

Source: Energy Poverty Survey

Out of the 581 households (90.7%) reported to be using firewood, 53.4% reported that they buy firewood, 41% reported that they collect it , whereas 5.7% reported that they do both. Analysis at district level shows that Multan district leads in buying: 97.7% rural households buy firewood. In Rawalpindi district 98% of the rural households reported to be collecting firewood. In district Chakwal, more than 11% rural household reported they both collect and buy firewood, which is more than in all other districts.

We mentioned earlier that household size affects the buying and/or collecting frequency of a particular energy source for a given household. In order to compare households, we have standardised the buying and/or collecting frequency by dividing it by household size, which gives us the standardised (or per capita) value for buying and/or collection frequency for a given energy source *j* in a given household *h*. To represent a standardised indicator, we represent it with a bar.

Using the formula in equation 5 and considering $X_i = \overline{BFI}$, we can compute the *buying (collection) frequency index (* $\overline{BFI}$) as following:

$$\overline{BFI}_{hj} = \frac{BF_{hj} - BF_{j(\min)}}{BF_{j(\max)} - BF_{j(\min)}} \quad \mathbf{8}$$

Whereas, BFI_{hj} is a value given for buying frequency (or collection frequency) per capita for a given energy source *j* in a household *h*.

4.2.2. Distance Covered

Household distance refers to the distance which has to be travelled by household members to access certain energy source. An ordinal scale representing the range of distances is used, where 1 represents a distance of less than 500 meters and 5 represents more than 5 kilometres (see table 4). Distance has been referred to as one of the major impediments to choosing certain energy sources or preferring one energy choice over others. In some cases, the rural households have to travel long distances to acquire a source of energy and then return to their dwelling. Households with higher incomes and convenient access to traditional biomass prefer to use traditional biomass rather than to switch towards LPG which requires them to travel from their community to a nearby town or city. In such a case households have to pay a 'premium' for using a modern energy source like LPG, by spending extra time, effort and commuting costs.

In the case of animal waste, we found that rural households have most convenient access to animal waste. This is due to the fact that most rural households, with or without livestock ownership, have their animal waste stock at or near their dwelling. Rural households without livestock ownership and in the need of animal waste as an energy source, still have convenient access as it is easily available within community.

Table 4: Inconvenience Scores for Household Distance

	1	*2*	*3*	*4*	*5*
Household Distance	Less than 500m	More than 500m but less than 1km	More than 1km but less than 3km	More than 3km but less than 5km	More than 5km

Source: Energy Poverty Survey

To compute the *Household Distance Index (HDI)* for an energy source *j* used by household *h*, we can write the equation as following,

$$HDI_{hj} = \frac{HD_{hj} - HD_{j(\min)}}{HD_{j(\max)} - HD_{j(\min)}} \qquad 9$$

Where HDI_{hj} represents the household response for household distance travelled for a given energy source *j*, whereas $HD_{j(min)}$ and $HD_{j(max)}$ represents the sample minimum and maximum scores for household distance travelled for a given energy source *j*, respectively.

4.2.3 Means of transport used

We found that people use different means of transport to access energy sources, depending on their income, type and proximity of energy sources. Nearly 43% of rural households using firewood reported that they transport firewood by foot when they buy firewood, against 78% of households when firewood is collected. The second next option in both cases (firewood bought and collected) also differs. When firewood is bought, 33.8% people reported that they use bicycles to transport, whereas in when firewood is collected, people also use animal carts for transportation.

As regards animal waste, 97% households reported that they transport it by foot. This high percentage is due to the fact that the cattle sheds are mostly part of rural household dwelling. In the case, when households buy animal waste, the most common mode of transportation is still by foot, as people use informal means to buy it from neighbours in the same community.

The means of transport used in plant waste slightly differs from those used in the case of animal waste. Of households that are using plant waste as one of their main energy source, 55.1% and 38.2% reported that they are transporting it by using foot and animal carts.

Table 5: Inconvenience Scores for Means of Transportation

	1	*2*	*3*	*4*	*5*	*6*	*7*
Means of Transportation	tractor	cart (animal)	car	public transport	motorbike	bicycle	by foot

Source: Energy Poverty Survey

Different scores are assigned to different means of transport, which depends on its convenience level (see table 5). Using the data for means for transportation, the means of transport index can be computed as,

$$MTI_{hj} = \frac{MT_{hj} - MT_{j(\min)}}{MT_{j(\max)} - MT_{j(\min)}} \qquad \textbf{5.10}$$

Where MTI_{hj} represents the household response for means of transport used to access a given energy source *j*, whereas $MT_{j(min)}$ and $MT_{j(max)}$ represents the sample minimum and maximum scores for means of transportation used to access a given energy source *j*, respectively.

4.2.4 Household Involvement

One of the major indicators of inconveniences associated with accessing energy sources is household involvement. This refers to the number of household members involved in collecting, buying and transporting particular energy source to the dwelling. Household involvement is also dependent on the type of energy source. It has been observed that traditional biomass often requires more household involvement compared to LPG.

Table 6: Inconvenience Scores for Household Involvement

	1	*2*	*3*	*4*
Household Involvement (uncontrolled)	Only 1 member	2 members	3 members	More than 3 members

Source: Energy Poverty Survey

Depending on the type of energy sources, household involvement differs across rural households. In the case of LPG, the score could be a maximum of 2 which is equal to 2 household members, whereas in other cases, like firewood, the score can be 4[7], representing more than 3 household members involved in collection and/or buying at one time.

As mentioned earlier, we adjust the household involvement indicator for household size. Therefore instead of using household involvement per household, we used household involvement per capita for a given household *h*. Once again, this index is represented with the bar.

Household involvement index is computed as following,

$$\overline{HII}_{hj} = \frac{HI_{hj} - HI_{j(\min)}}{HI_{j(\max)} - HI_{j(\min)}} \qquad \textbf{11}$$

$\overline{HII}_{hj}$ refers to the number of household members per capita involved in buying and/or collecting energy source *j* in a given household *h*.

4.2.5 Time Spent

Time spent refers to hours spent per week by a given household to acquire a certain type of energy source. For each energy source, we asked households about the number of hours per week spent by an individual in buying or collecting a certain energy source. To calculate the total household hours spent on a certain energy source, we multiplied the time (hours per week spent on a certain energy source by a household member) by household involvement for a certain energy source. Here it is also important to mention that acquiring a specific energy source includes all the activities from leaving home, commuting to and fro and collecting or buying an energy source.

Figure 2 shows how much time per household member per week different income groups are spending on average on different energy sources. We can see that for the lowest income group, the energy source with highest burden in terms of time is animal waste. For the lower, middle, upper middle and upper income groups, plant wastes turned out to be the most time consuming energy source, whereas LPG turned out to be the one with the least burden of time for all income groups.

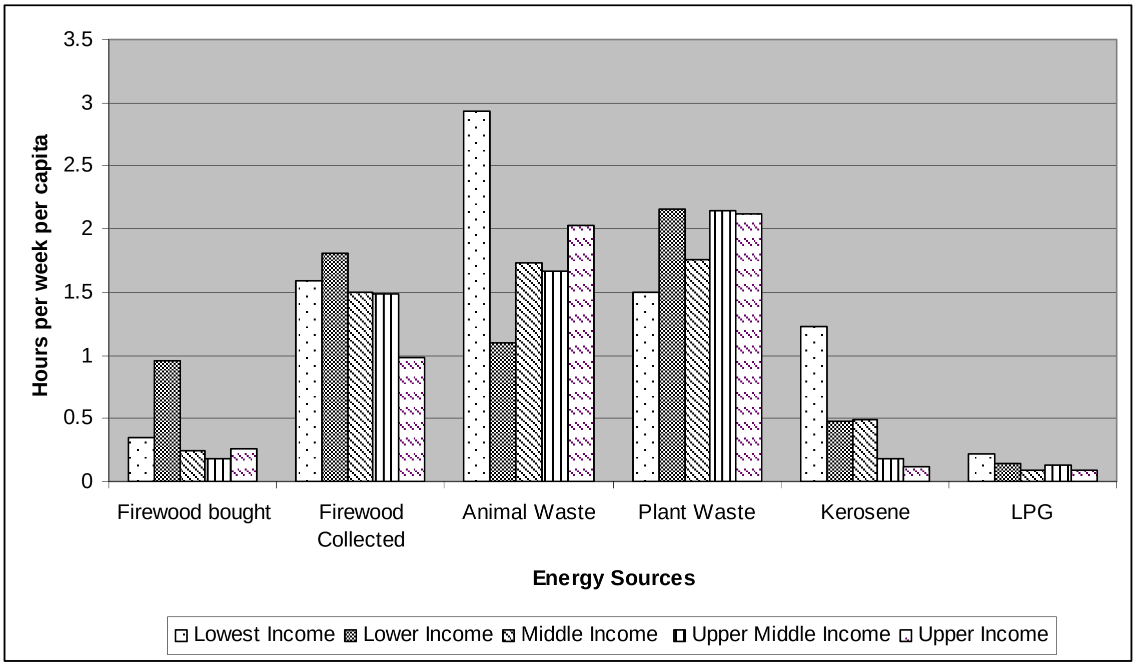
The Time index is based on the hours people are spending (per week) on collection and/or buying energy sources. We found that apart from its dependence on the type of energy source used by a household, time spent per week in collection and/or buying is also dependent on the proximity of energy source, and remoteness of the rural community. However this is not entirely

[7] In our survey, an insignificant number of households reported that more than 3 household members went out for buying or collecting certain energy source (Fb=6 households (0.6%), Fc=9 (3.3%), Aw= 6 (1.6%), Pw=6 (5.5%), K= 0, LPG= 0). For our calculations, we assumed that those households which responded 4 against the household involvement question might send 4 members to buy or collect a certain energy source. This means that the household involvement value 4 not only represents 4 household members, but also represents the highest inconvenience in terms of household involvement.

true in the case of household using animal waste, whereby despite its convenience access in or nearby their dwelling, households spent several hours processing animal waste, which includes collection, cleaning, drying and recollection of dried animal waste.

In the case of time, we have not only adjusted it for household size, but we have also controlled it for household involvement, as total household hours depends on the number of household members involved in buying and/or collecting certain types of energy sources. After adjusting for household size and household involvement, the index is represent as $\overline{TI}_j$.

Figure 2: Hours spent per week per capita on energy sources in different income groups



Source: Energy Poverty Survey

Using data for time spent per week per household member for each energy source in a given household, the time index can be computed as follows,

$$\overline{TI}_{hj} = \frac{T_{hj} - T_{j(\min)}}{T_{j(\max)} - T_{j(\min)}} \qquad \textbf{12}$$

Instead of assigning scores, the time index is computed on the base of actual number of hours spent per week mentioned by the respondents for each energy source, *j* divided by household size. TI_{hj} represents the household response in hours spent per week per capita, whereas $T_{j(min)}$ and $T_{j(max)}$ represent the sample minimum and maximum hours spent per week per capita for a given energy source, *j* in a household *h*.

4.2.6 Household Health

In the EPS, we asked whether households experienced any health problems due to the use of certain energy sources. The question was only asked to traditional biomass users, and not to kerosene and LPG users. We assumed that kerosene and LPG users do not experience any health problems.

In our sample, 53% households reported that they experience health problems by using firewood, whereas 47% reported that they do not have any health problems while using firewood. Similarly for animal wastes, 56.6% of rural household answer that using animal waste is not injurious to their health, whereas more than 43% considered it as injurious to their health. For plant wastes, 53.7% rural households considered that using plant wastes has no health effects, whereas 46.3% rural households assume that it has negative health effects.

Table 7: Inconvenience Scores for Health Effects and Children Involvement

	0	*1*	*2*
Health Effects	No effects	Negative effects	
Children Involvement	No involvement	Partial Involvement	Full Involvement

Source: Energy Poverty Survey

For computing *the Household Health Index* (HHI), *no effects* was assigned a score of 0, whereas *negative effects* were assigned as score of 1 (see table 7). Following the equation 1, we get the following equation for the *Household Involvement Index*:

$$HHI_{hj} = \frac{HH_{hj} - HH_{j(\min)}}{HH_{j(\max)} - HH_{j(\min)}} \quad \mathbf{13}$$

This means that the household health index will take the values 1 or 0.

4.2.7 Children Involvement

In our survey, children are defined as all household members below the age of 12 years. In the EPS, we asked households about their children's involvement in buying and/or collection of different energy sources used by a household. When asked whether children are involved in buying and/or collection, households may respond in three ways: no involvement, partial involvement and full involvement (see Table 7 & 8). In our sample, we found that firewood has the highest degree of children's involvement at 3.6% followed by plant waste (2.3%), kerosene (2.2%) and animal waste (1.6%). With regard to the response of partial involvement, 10% of the households involve their children in buying kerosene as compared to 8.3% in buying or collecting firewood. LPG has the lowest involvement of children with only 0.5% households partially involving their children in buying LPG.

Table 8: Sample response for Children Involvement for different energy sources (%)

	*Firewood**	*Animal Waste*	*Plant Waste*	*Kerosene*	*LPG*
No Involvement	88.1	93.3	94.4	87.8	99.5
Partial Involvement	8.3	5.2	3.3	10	0.5
Full Involvement	3.6	1.6	2.3	2.2	-

* Response includes firewood collected and bought.
Source: Energy Poverty Survey

To compute the *children involvement index (CII),* equation 5.1 can be written as following:

$$CII_{hj} = \frac{CI_{hj} - CI_{j(\min)}}{CI_{j(\max)} - CI_{j(\min)}} \qquad \mathbf{14}$$

Where CII_{hj} represents the household response for a specific energy source j, $CI_{j(min)}$ represents the sample minimum, which equals to 0, implying no children involvement, and $CI_{j(max)}$ represents the maximum value for children involvement in a given energy source j.

4.3 New Indicators of Energy Poverty: A Summary

Our approach to the measurement of energy poverty results in a rich set of indicators which can be used for further research and analysis. First we have the final Energy Poverty Index (EPI) which can be used to calculate a headcount of the households that are in energy poverty in a given community or district. The EPI also measures the severity of energy poverty for each household. In a similar way, the two sub-indexes for Energy Shortfall (ES) and the Energy Inconvenience Excess (EIE) can be used to calculate headcounts as well degrees of excess inconvenience or energy shortfalls.

In addition to this, we can also use the original index of total energy inconvenience (TEI) and the measure of *actual energy consumption* (AEC) to analyze the differences between households, communities and districts.

5. Measurement of Energy Poverty: Results

In this section, we present substantive results and analyses of energy poverty. The results will be broken down by income group, village and district. In general, the results for the EIE, ES and EPI indicate that 23.1% of the rural households in our sample experience serious energy inconveniences, 96.6% experience energy shortfalls and 91.7% are in a condition of energy poverty.

Table 9 shows the data for the *Energy Inconvenience Index (EII)* for each of the energy sources as well as the *Total Energy Inconvenience Index* (TEI), broken down by income groups. The mean values of EII for each energy source are weighted averages of the household scores in energy inconvenience indicators. The weights correspond to the share of an energy source (in kilowatt hours) in household energy use (total energy in kilowatt hours). In this way, we are also able to control for the actual inconvenience that incurs by a given household for using particular amount of energy source. This means that a household with a higher share of collected firewood will incur higher inconveniences associated with firewood than a household using less collected firewood. If this is not controlled for, all households using collected firewood, irrespective of the share of collected firewood, would receive the same weight. This would produce biased results.

We see that the upper income households experience the least inconvenience associated with accessing firewood bought (*EII=0.297*) whereas the lower income group experience the highest inconvenience (*EII=0.347*). This is due to the fact that rural households in lower income group have higher shares of firewood bought in their total energy supply as compared to other income groups. Similarly, in the case of firewood collected, the upper income group experiences the least inconvenience in accessing collected firewood (*EII=0.279*). In this case, the highest inconveniences are borne by lower income group, which are equal to 0.375 index value, which might be due to different reasons including the amount of firewood collected and its respective values on inconvenience indicators.

The results for animal waste shown in table 9 are consistent with our analysis of the functioning of rural energy markets in (see section 3.2 How Rural Energy Markets Function). Despite of having lower livestock ownership, the lowest income group is experiencing the highest inconveniences in animal waste access (*EII=0.322*). As mentioned earlier, poor households often help richer households with higher livestock ownership in processing animal waste, receiving free animal waste access in return. In the case of higher income groups, the *EII* value is influenced by their higher livestock ownership, but is lower than thatfor the lowest income group.

Table 9: Energy Inconvenience Index (EII) for each energy source and Total Energy Inconvenience Index, by income group (mean values)

	Firewood bought	***Firewood Collected***	***Animal Waste***	***Plant Waste***	***Kerosene***	***LPG***	***TEI****
	Mean EII Scores						
Lowest Income	0.34	0.35	0.32	0.35	0.36	0.40	2.12
Lower Income	0.34	0.37	0.28	0.35	0.33	0.40	2.07
Middle Income	0.31	0.34	0.28	0.32	0.34	0.35	1.94
Upper Middle Income	0.30	0.32	0.26	0.31	0.32	0.34	1.85
Upper Income	0.29	0.27	0.28	0.22	0.26	0.32	1.64
Total	0.32	0.33	0.28	0.31	0.32	0.36	1.92

* The Mean EII is the weighted average of household scores, with the share of energy source in total energy use as weight.
The mean value TEI is an unweighted average of household scores.
Source: Energy Poverty Survey.

In the case plant waste, we see a gradual decrease in inconvenience scores, as the income increases. Although, richer households have higher land ownership and consequently larger fields with potential plant waste, the inconvenience scores are low. We attribute this also to rural energy market structure, where poor households without land ownership are involved in helping out richer households with land ownership and receive plant wastes, which they can use as a source of energy. In the case of kerosene, the lowest income group experiences highest level of inconveniences as compared to other income groups. The same is true in the case of LPG, where lowest and lower income groups have same inconvenience index values, implying the same degree of inconvenience for both poor groups. On the other hand, LPG access is much more convenient for the upper income group, due to their better scores on inconvenience indicators.

Table 10: Inconvenience Indicator Contributions in EEI by Energy Source and Income

	Lowest Income	*Lower Income*	*Middle Income*	*Upper Middle Income*	*Upper Income*	*Mean*
Firewood Buying						
Buying Frequency	15.50%	13.40%	11.20%	9.50%	8.60%	11.60%
Means of Transport	32.00%	31.90%	33.30%	37.10%	35.40%	33.90%
Distance Travelled	11.30%	14.50%	18.80%	17.10%	20.50%	16.40%
Household Involvement	19.50%	15.60%	13.00%	11.40%	9.80%	13.90%
Time Spent	1.00%	2.50%	0.70%	0.60%	0.70%	1.10%
Health Effects	18.80%	19.60%	21.00%	23.40%	22.90%	21.10%
Children Involvement	1.90%	2.40%	2.00%	1.00%	2.20%	1.90%
Total	100%	100%	100%	100%	100%	
Firewood Collection						
Collection Frequency	11.30%	10.10%	8.10%	6.60%	5.60%	8.30%
Distance Travelled	6.20%	10.70%	12.90%	17.60%	21.80%	13.80%
Means of Transport	39.00%	36.00%	36.80%	36.40%	32.40%	36.10%
Household Involvement	8.20%	8.30%	8.50%	7.30%	8.40%	8.20%
Time Spent	2.70%	2.90%	2.50%	2.30%	2.70%	2.60%
Health Effects	23.50%	25.30%	24.80%	24.40%	23.40%	24.30%
Children Involvement	9.00%	6.70%	6.30%	5.40%	5.60%	6.60%
Total	100%	100%	100%	100%	100%	
Animal Waste						
Collection Frequency	21.10%	16.80%	15.20%	15.10%	14.10%	16.50%
Distance Travelled	4.90%	3.20%	3.30%	4.40%	4.90%	4.10%
Means of Transport	32.00%	39.70%	42.30%	43.60%	43.10%	40.10%
Household Involvement	13.90%	13.70%	12.40%	10.10%	9.60%	11.90%
Time Spent	9.30%	3.40%	4.90%	4.60%	6.40%	5.70%
Health Effects	17.20%	20.00%	18.90%	21.50%	20.60%	19.60%
Children Involvement	1.70%	3.30%	3.00%	0.80%	1.30%	2.10%
Total	100%	100%	100%	100%	100%	
Plant Waste						
Collection Frequency	32.70%	29.30%	37.20%	28.50%	39.50%	3.90%
Distance Travelled	6.40%	5.80%	3.80%	2.80%	0.40%	33.40%
Means of Transport	14.60%	16.00%	10.80%	12.60%	4.30%	25.60%
Household Involvement	23.40%	18.80%	23.50%	22.10%	40.40%	13.70%
Time Spent	8.50%	13.20%	11.60%	20.60%	14.70%	8.30%
Health Effects	10.60%	11.20%	10.10%	8.70%	0.80%	3.40%
Children Involvement	3.80%	5.60%	3.00%	4.80%	0.00%	3.90%
Total	100%	100%	100%	100%	100%	
Kerosene						
Distance Travelled	22.70%	28.00%	22.60%	20.50%	13.60%	21.50%
Means of Transport	30.10%	30.30%	28.80%	32.10%	37.10%	31.70%
Household Involvement	25.90%	25.20%	31.80%	30.90%	37.60%	30.30%
Time Spent	8.10%	3.70%	4.80%	2.50%	1.70%	4.10%
Health Effects	8.00%	8.20%	7.50%	8.50%	5.20%	7.50%
Children Involvement	5.20%	4.60%	4.50%	5.50%	4.70%	4.90%
Total	100%	100%	100%	100%	100%	
LPG						
Distance Travelled	5.00%	12.30%	17.30%	23.20%	29.00%	17.40%
Means of Transport	6.00%	16.00%	24.60%	30.50%	35.20%	22.50%
Household Involvement	41.60%	45.20%	39.70%	26.00%	22.40%	35.00%
Time Spent	47.40%	26.50%	16.80%	20.30%	12.90%	24.80%
Children Involvement	0.00%	0.00%	1.60%	0.00%	0.60%	0.40%
Total	100%	100%	100%	100%	100%	

Note: Percentages are derived from the values given in Table 9 and their corresponding index values for each energy inconvenience indicator. For graphical illustration of Table 10, a bar chart is included in the Annex.
Source: Energy Poverty Survey

Table 10 shows the contribution of each type of inconvenience in the energy inconvenience index (EII) of rural households across all income groups and energy sources. As in the lowest income group, we see that 32% of the energy inconvenience comes from inconvenient means of transportation used by rural households while buying firewood. For firewood buying, the share of means of transport is consistent across all income groups. On the other side, an interesting trend can be noticed in the household involvement, which continues to decrease from 19.5% in lowest income group to 9.8% in upper income group, implying that rural household tend to shift from inconvenient means of transport to more convenient ones, as their income rises.

Similarly, in the case of firewood collection, means of transport indicator contributes major portion in total energy inconvenience across all income groups. As mentioned earlier, we may expect that richer household might own better modes of transport than poor households, but still one-third (upper middle income = 36.4%; upper income = 32.4%) of energy inconveniences are attributed to means of transport used. This share of energy inconvenience from means of transport actually rises when households use animal waste, due to the fact that most animal waste users transport it by foot (the most inconvenient mean of transport). In that case, richer households reported higher inconveniences from means of transport in animal waste than those of firewood collection (increased to 43.1% in animal waste as compared to 32.4% in firewood collection).

On contrary, the share of means of transport when plant waste is used declines across all income groups from 14.6% in lowest income group to 4.3% in upper income group. Instead, the major component in energy inconvenience for plant waste turned out to be the collection frequency and household involvement. Across all income groups, both of these indicators contributed to energy inconvenience index from 56.1% in the lowest income group to 79.9% in the upper income group.

In the case of kerosene, three major inconvenience indicators came up as the major contributors in energy inconvenience index: distance travelled means of transport and household involvement. Across all income groups, they contributed nearly 80% of inconveniences to energy inconvenience index. In the case of LPG, four major contributors to energy inconvenience index came up in higher income groups (as they are the main users): distance travelled means of transport, household involvement and time spent. In upper middle income group, all these four indicators contributed to 100% inconvenience, with major portion of inconvenience added by means of transport indicator. Children involvement in this income group remained 0. Similarly, in the case of upper income group, these indicators contributed to 99.4% of inconvenience, where means of transport is having highest contribution in energy inconvenience index with 35.2% value.

Table 11 shows the mean *EII* values for each energy source across different villages and districts. The table allows us to compare inconveniences and to see which villages or districts provide better energy access than others. In terms of convenience for accessing bought firewood, Layyah district has the lowest EII value of 0.23, implying that buying firewood is the most convenient in this district as compared to others. Multan and Muzaffargarh districts turned out to have the highest values for the *EII* (both 0.35), implying that households incur the highest degree of inconveniences in these districts when buying firewood.

Table 11: Energy Inconvenience Index (EII) for each energy source and Total Energy Inconvenience, by village and district (mean values)

		Firewood bought	*Firewood Collected*	*Animal Waste*	*Plant Waste*	*Kerosene*	*LPG*	*TEI*
District	Village							
Chakwal	Chawintra	0.34	0.31	0.26	0.32	0.31	0.41	1.95
	Dhok Wadan	0.35	0.32	0.28	0.36	0.27	0.39	1.97
	Mona	0.25	0.36	0.29	0.26	0.25	0.29	1.70
Chakwal District Average		0.31	0.33	0.27	0.31	0.27	0.36	1.87
Faisalabad	243Roshan Wala	0.30	0.35	0.26	.	.	0.37	1.28
	Dasuha	0.34	0.38	0.31	.	0.25	0.3	1.58
	Ram Diwali	0.30	0.35	0.31	.	.	0.39	1.35
Faisalabad District Average		0.31	0.36	0.29		0.25	0.35	1.40
Gujrat	Panjoria	0.24	0.21	0.22	.	0.28	0.32	1.27
Jhelum	Bagga	0.32	0.34	0.26	.	0.27	0.38	1.57
	Nogaran	0.28	0.28	0.25	.	0.26	0.37	1.44
Jhelum District Average		0.30	0.31	0.25		0.27	0.38	1.50
Lahore	Salam Nagar	0.33	0.34	0.29	.	.	0.31	1.27
	Sham ke Bhatiyan	0.29	0.31	0.29	.	.	0.30	1.19
Lahore District Average		0.31	0.32	0.29			0.30	1.23
Layyah	Ali Alla	0.31	0.33	0.22	0.28	0.38	.	1.52
	Bangalwali	0.11	0.25	0.30	0.19	0.34	.	1.19
	Basti Tilkan	0.27	0.35	0.31	0.29	0.35	.	1.57
Layyah District Average		0.23	0.31	0.28	0.25	0.36		1.42
Multan	Allahbad	0.38	0.21	0.28	.	.	0.37	1.24
	Kikkar Wala	0.33	.	0.23	.	.	0.42	0.98
Multan District Average		0.35	0.21	0.26			0.40	1.11
Muzaffargarh	Basti Colony	0.35	0.52	0.30	0.49	0.43	.	2.09
	Basti Hayat Wala	0.35	0.46	0.41	0.36	0.33	.	1.91
	Basti Jhandair	0.34	0.49	0.38	0.50	0.40	.	2.11
Muzaffargarh District Average		0.35	0.49	0.36	0.45	0.39		2.03
Rawalpindi	Dhok Khorian	.	0.37	0.29	.	0.29	.	0.95
	Dhok Narian	.	0.35	0.35	.	0.34	.	1.04
Rawalpindi District Average			0.36	0.32		0.32		0.99
Sheikhupura	Kadlathi	0.32	0.26	0.23	.	0.24	0.28	1.33
	Lallu Phuman	0.31	0.30	0.26	.	.	0.39	1.26
	Nawan Kot	0.35	0.34	0.26	.	.	0.29	1.24
Sheikhupra District Average		0.33	0.30	0.25		0.24	0.32	1.27
Sialkot	Jalfan Wali	0.30	0.30	0.24	.	0.31	0.34	1.49
	Kot Karam Bakhsh	0.29	0.29	0.25	.	0.21	0.32	1.36
	Palora Kallan	0.27	0.34	0.23	0.29	0.22	0.30	1.65
Sialkot District Average		0.29	0.31	0.24	0.29	0.25	0.32	1.50
Total		0.30	0.32	0.28	0.33	0.29	0.34	1.42

Note: Table gives index values computed on the methodology explained in section 4, for each energy source across villages/communities surveyed and their corresponding districts. Energy Inconvenience Index values are relative to our assumed energy inconvenience value of 0.00 for electricity and natural gas.
Sample Size = 640, total household members = 4816. For the calculation of the means, see footnote to table 9.
Source: Energy Poverty Survey

Similarly in the case of collected firewood, Multan district has the lowest value for the EII (0.21), though households in only 1 village of Multan district reported that they collect firewood (see Table 11). The most inconvenient district with respect to collecting firewood is Muzaffargarh, where the average score for *EII* is 0.49. For animal waste, Muzaffargarh district turned out to have the highest *EII* value of 0.36, whereas Gujrat district had the lowest *EII* value of 0.22. In the case of LPG, results show that it is the most inconvenient to use LPG in Multan district as the *EII* value is 0.40. On the other hand, the most convenient district to use the LPG is the Lahore district, where the *EII* value is 0.30.

The frequency table for the *EIE* reveals that 23% of the rural population experiences severe energy inconveniences above the threshold levels whereas 77% is below the threshold level, but still experience energy inconvenience while meeting their household energy needs. This shows that accessing traditional energy sources in rural communities requires high degrees of effort and inconvenience along all dimensions of the inconvenience indicators. This clearly implies that energy access in rural areas has high opportunity costs. With regard to the energy shortfall (*ES)*, the situation is even worse. 99.4% of rural households experience extreme energy shortfall (in kilowatt hours), whereas only 0.6% rural households are above the minimum energy requirements. Lastly, as regards the energy poverty index among rural households, the situation is equally bad. Despite of having threshold 30% (TEIT) above the mean TEI, 97.3% rural households are categorized as extreme energy poor with severe EPI, whereas only 2.7% rural households can be categorized as non-energy poor households.

Table 12 shows the mean values for the EIE and the *ES* along with the % of households below the poverty threshold in each income category. With regard to the EIE, we see that om average the lower income group has lower values of EIE (positive sign) *(EIE=10.40)* than other income groups. The value of 10.49 implies that households in the lower income group are on average 10.40% above the threshold value of inconveniece, which is equal to 0.32 (see equation 4). This low average value means that many households fall below the inconvenience threshold. We can also see in table 12, that 34.1% and 32.8% of our sample in the lowest and lower income groups respectively, experience high degrees of inconvenience with respect to their energy choices. Furthermore, as expected, the lowest degree of energy 'convenience' (due to positive sign) is experienced by the lowest income groups: 11.0% and 10.4%, whereas the upper income group value of 32.3% shows that they have most convenient energy access. Similarly, according to HCI (head count index), 34.1% of the lowest income group are experience excessive energy inconveniences against 11% in the upper income groups.

In the case of the energy shortfall (ES), the largest energy shortfall occurs in the lower income group with a value of -72.8%, whereas the lowest energy shortfall is experienced by the upper income group with a value of -65.6%. In terms of percentages of households below the energy shortfall threshold, once again lowest income group turned out to be the most affected group with 99.3% energy shortfalls. But even in the richer households the headcounts for energy shortfall are very high: 98.5% and 97.0% in upper middle income and upper income groups respectively. This implies that despite of better household incomes in richer households, energy shortfall is still a major problem. Although, the degree of energy shortfall (ES Mean Values) continues to fall as the household income grows, very large numbers of households in higher income groups are still not able to meet their growing energy needs as their income rise.

Table 12: Energy Poverty by income group

	Energy Inconvenience Excess (EIE)		*Energy Shortfall (ES)*		*Energy Poverty Index (EPI)*	
	Mean (%)	**HCR(%)**	**Mean (%)**	**HCR(%)**	**Mean (%)**	**HCR(%)**
Lowest Income	11.0	34.1	-70.3	99.3	-29.6	92.8
Lower Income	10.4	32.8	-72.8	97.4	-31.2	95.8
Middle Income	19.4	24.1	-72.4	97.8	-26.5	93.4
Upper Middle Income	30.4	13.6	-69.8	98.5	-19.6	92.6
Upper Income	32.2	11.0	-65.6	97.0	-16.7	91.1
Total*	22.8	19.5	-70.0	97.9	-23.5	92.8

* Sample Mean; Sample Size = 640, total household members = 4816.
Note: Negative percentages denote inconveniences, shortfalls and poverty, whereas positive percentages denote conveniences, excess and prosperity for EIE, Energy Shortfall and EPI respectively.
Energy Inconvenience Threshold Level or Inconvenience Line = 0.323; Energy Shortfall Threshold or Line = 156.55/capita/week (based on 0.7TOE/capita/annum requirements);
Lowest Income Group = Rupee (Re) 1. till Rupees (Rs) 3000; Lower Income Group = Rs. 3001-5000; Middle Income Group = Rs. 5001-8000; Upper Middle Income Group = Rs. 8001-12000; Upper Income Group = Rs. 12001 and above
Source: Energy Poverty Survey

On the other hand, the *EPI* values show that the lower income group is not only the most energy poor group with a value of -31.2%, but also has highest number of energy poor households (95.8%). As expected, the upper income group is not only relatively least energy poor group with mean values of -16.7% but also has lowest percentage of energy poor households (91.1%).

Table 13 provides a breakdown of our indicators by districts and villages. In this table, negative values of *EIE* indicate excess inconvenience whereas positive values indicate levels of ‘convenience’. We see that Basti Hayat Wala village in the Muzaffargarh district has the highest degree of energy inconvenience, with an *EIE* value of -16.9%. As regards the HCI for this village, 0.6 value implies that 60% of their population is experiencing severe energy inconveniences, which is relatively better than Dhok Khorian of Rawalpindi district, as it has 80% of its population with severe energy inconveniences.

Table 13: Energy Poverty across different districts and villages

		Energy Inconvenience Excess (EIE)		Energy Shortfall (ES)		Energy Poverty Index (EPI)	
Districts	**Village**	**Mean**	**HCI***	**Mean**	**HCI**	**Mean**	**HCI**
Chakwal	**Chawintra**	34.5	0.1	-78.3	1.0	-21.9	0.9
	Dhok Wadan	27.5	0.2	-69.7	1.0	-21.1	1.0
	Mona	43.5	0.1	-77.0	1.0	-16.8	0.9
Chakwal District Average		35.2	0.1	-75.0	1.0	-19.9	0.9
Faisalabad	**243Roshan Wala**	37.8	0.1	-65.4	0.9	-13.8	0.8
	Dasuha	19.4	0.3	-69.4	1.0	-25.0	1.0
	Ram Diwali	25.2	0.2	-61.3	0.9	-18.1	1.0
Faisalabad District Average		27.5	0.2	-65.4	0.9	-19.0	0.9
Gujrat	**Panjoria**	48.9	0.0	-78.8	1.0	-14.9	1.0
Jhelum	**Bagga**	38.4	0.0	-68.6	1.0	-15.1	0.9
	Nogaran	32.1	0.1	-67.7	0.9	-17.8	0.9
Jhelum District Average		35.2	0.0	-68.2	0.9	-16.5	0.9
Lahore	**Salam Nagar**	38.2	0.0	-74.3	1.0	-18.0	0.9
	Sham ke Bhatiyan	34.1	0.1	-69.9	1.0	-17.9	0.9
Lahore District Average		36.2	0.0	-72.1	1.0	-18.1	0.9
Layyah	**Ali Alla**	0.0	0.5	-94.3	1.0	-47.1	1.0
	Bangalwali	9.6	0.3	-52.4	0.9	-21.4	0.9
	Basti Tilkan	3.1	0.5	-72.4	1.0	-34.6	1.0
Layyah District Average		4.2	0.4	-73..0	0.9	-34.4	0.9
Multan	**Allahbad**	15.7	0.2	-69.0	1.0	-26.7	0.9
	Kikkar Wala	25.3	0.1	-73.5	1.0	-24.1	0.9
Multan District Average		20.5		-71.3	1.0	-25.4	0.9
Muzaffargarh	**Basti Colony**	-10.9	0.3	-90.1	1.0	-50.5	0.9
	Basti Hayat Wala	-16.9	0.6	-45.3	0.9	-31.1	0.9
	Basti Jhandair	4.1	0.5	-66.8	0.9	-31.4	1.0
Muzaffargarh District Average		-7.9	0.4	-67.4	0.9	-37.7	0.9
Rawalpindi	**Dhok Khorian**	-12.5	0.6	-73.1	1.0	-42.8	1.0
	Dhok Narian	-10.9	0.8	-77.0	1.0	-44.0	1.0
Rawalpindi District Average		-11.7	0.7	-75.1	1.0	-43.1	0.9
Sheikhupura	**Kadlathi**	32.2	0.0	-73.6	1.0	-20.7	1.0
	Lallu Phuman	28.3	0.1	-62.7	1.0	-17.2	0.9
	Nawan Kot	29.0	0.1	-79.4	1.0	-25.2	1.0
Sheikhupura District Average		29.8	0.1	-71.9	1.0	-21.0	0.9
Sialkot	**Jalfan Wali**	39.7	0.1	-65.3	1.0	-12.8	0.9
	Kot Karam Bakhsh	38.7	0.0	-56.9	1.0	-9.1	0.8
	Palora Kallan	33.0	0.2	-59.7	1.0	-13.3	0.8
Sialkot District Average		37.1	0.1	-60.6	1.0	-11.7	0.8
Total		22.8	19.5	-70.0	97.9	-23.5	92.8

Sample Size = 640, total household members = 4816.
Note: Negative percentages denote inconveniences, shortfalls and poverty, whereas positive percentages denote conveniences, excess and prosperity for EIE, Energy Shortfall and EPI respectively.
*HCI= Head Count Index. Energy Inconvenience Threshold Level or Inconvenience Line = 0.323; Energy Shortfall Threshold or Line = 156.55/capita/week (based on 0.7TOE/capita/annum requirements).
Source: Energy Poverty Survey

On the positive side, we have Panjoria in Gujrat district and Mona in Chakwal district with mean *EIE* values of 48.9% and 43.5% respectively, implying that households, on average, in these villages have relatively 'convenient' energy access compared to other communities in our sample. Also in terms of their HCI, we can see that not a single household in Panjoria village is experiencing energy inconvenience excess (HCI=0.0), while only 10% of households in Mona village have severe problems in energy access.

In the case of the energy shortfall (*ES)*, the highest level of energy shortfall is reported in Ali Alla village of Layyah district with an average shortfall of nearly 94.3%. On the other hand, *Basti Hayat Wala* village of the Muzaffargarh district had the lowest values for energy shortfall (-45.3).

In the column of the HCI for *Energy Shortfall (ES)*, we see that all of the individuals from our sample of households across 27 villages are poor in terms of energy access in kilowatt hours. The headcount indicates that between 90-100% of the households are experiencing severe energy shortfalls.

Once the EPI is computed by taking the average of the *EIE* and the ES, we see that Kot Karam Bakhsh village of Sialkot district turned out to be the least energy poor with the value of -9.1% and headcount of 80%. On the other side, Basti Colony village in the Muzaffargh district turned out to be the most energy poor village with value of -50.5%.

5.1 Comparison of Indexes with the Energy -Income Indicators

We finallly compared our new EPI indicator, with a more conventional indicator, the energy expense excess which is calculated on the basis of the share of energy expenses in household expenditure. Based on the household energy expenses per month and energy expense threshold set by DFID (UK) i.e., 10% of the household income, we can compute the energy expense excess.

Energy Expense Excess is computed by taking the difference of energy expense threshold (which is 10% of the household income) and actual percentage share of energy expenses in total expenditures for each household. A positive sign with the energy expense excess indicator indicates that the rural household is spending less than the 10% threshold, whereas a negative sign indicates that the energy expenses are higher than the given threshold.

Table 14: Comparison of Indexes with Energy- Income Indicators across Different Income Groups

	Energy Expense Excess (%)	*HCR (%)*	*EPI (%)*	HCR* (%)
Lowest Income	-21.00	71.5	-29.6	92.8
Lower Income	-15.62	57.5	-31.2	95.8
Middle Income	-15.31	71.5	-26.5	93.4
Upper Middle Income	-10.93	76.5	-19.6	92.6
Upper Income	-4.39	68.4	-16.7	91.1
Total*	-12.12	69.8	-23.5	92.8

* Sample Mean; Sample Size = 640, total household members = 4816.
Note: Negative percentages denote energy poverty, whereas positive percentages denote energy prosperity in Energy Expense Excess and EPI indicator only (and not for HCR columns).
Energy Inconvenience Threshold Level or Inconvenience Line = 0.323; Energy Shortfall Threshold or Line = 156.55/capita/week (based on 0.7TOE/capita/annum requirements).
Lowest Income Group = Rupee (Re) 1. till Rupees (Rs) 3000; Lower Income Group = Rs. 3001-5000; Middle Income Group = Rs. 5001-8000; Upper Middle Income Group = Rs. 8001-12000; Upper Income Group = Rs. 12001 and above.
Source: Energy Poverty Survey

In contrast to the EPI which points to substantial degrees of energy poverty even in the higher income groups (-19.6% and -16.7% in upper middle and upper income groups), we see that the more traditional indicator of energy expense excess shows much lower degrees of energy poverty. This is an interesting finding, as the expense indicator is often used in the literature as a measure of household energy poverty. We see that in spite of very low values on the energy expense excess in the upper income group households (-4.3%), the energy poverty index for that income group is quite high: -16.7%. What this shows is that richer households may spend less of their income on energy, but nearly one fifth of upper income household still remains in the state of serious energy poverty.

6. Conclusions and further research

In this paper, we have devised a new methodology to measure energy poverty in rural households. Applying this methodology, we have attempted to overcome shortcomings in the measurement of energy poverty by including indicators of the inconvenience associated with energy use. Our results show that rural households without natural gas but with or without electricity experience high energy shortfalls across all income groups, despite of their enormous physical and economic efforts to overcome energy shortage.

In the paper, we constructed different indexes to measure the inconveniences a household experiences, that are not only associated with the energy sources used, but also with the subsequent household energy mix. Following the methodology of Haq (1990) for the Human Development Index (HDI), we constructed separate indexes for each dimension of inconvenience. By taking the average of indexes for each energy source, we developed the *Energy Inconvenience Index* (EII) for each energy source used by rural households. Furthermore using the shares of each energy source in total household energy consumption as weights, we constructed an aggregate weighted energy inconvenience index for each household in our sample.

Subsequently, we computed a threshold level of 30% above the sample mean, referred to as the *Energy Inconvenience Threshold* (EIT) or – to use a term similar to the poverty line – the energy inconvenience line. The inconvenience line provides a benchmark for the inconveniences experienced by each energy poor household in our sample. It can be used to calculate the *Energy Inconvenience Excess* (*EIE*). Comparable to a poverty gap measure, the *EIE* measures the gap between the actual inconveniences suffered by households and the inconvenience line.

On the other hand, using energy consumption data for each household calculated on the base of standard energy content (in kilowatt hours), we computed household energy shortfalls – the difference between the required energy (per capita per week) and actual energy consumption (per capita per week). Once the energy shortfall percentage for each household has been calculated, we calculated the *Energy Poverty Index (EPI) as* the unweighted average of the *Energy Shortfall* and the *Energy Inconvenience Excess (EIE)*.

One of the major objectives of this paper is to develop a universally acceptable indicator to measure widespread energy poverty in the developing world. We envisage that with the passage of time, the *energy poverty index* along with its two underlying indexes, the *energy inconvenience excess* and the *energy shortfall index* would provide a tool for assessing energy related development policies, specifically for rural areas of developing world. We believe that the inclusion of inconvenience associated with the use of each energy sources, in particular with traditional biomass, is important and relevant for our understanding of the complex phenomenon of energy poverty.

The inclusion of inconveniences in the analysis not only provides a social perspective on the meaning of energy poverty, but also allows for a better economic analysis. Higher inconvenience scores are an indication of higher opportunity costs associated with given sources of energy and different energy mixes. In this way, energy poverty has its impact on the potential of households to achieve higher incomes in the future.

A comparison between economic indicators based on energy expenses and the EIE, ES and the EPI confirms that most rural household are energy poor. But it also serves to highlight the various economic, social and physical factors involved in access to energy.

As regards future research, the approach still needs further refinement, in particular with regard to the calculation of inconveniences, threshold values and dealing with household composition. But the paper shows that it is possible to measure relative inconveniences and subsequently quantify household relative energy poverty, as expressed by EPI. This provides us with novel directions for future energy poverty and development related research. The indicators and results from this research provide us with a basis for a further investigation of the determinants not only of energy poverty, but also of energy inconveniences and energy shortfalls.

Annex 1: Energy Source Conversion Factors

To standardise the energy units according to Pokharel (2006) definition of energy poverty based on energy consumption of 1TOE per capita per annum, we converted it into kilowatt hours for comparison with our energy poverty data collected from the EPS. To make this threshold level relevant to energy consumption of developing countries and in particularly rural households, we took a subjective adjusted this threshold level to 0.7TOE per capita per annum.

Firewood bought

The EPS includes two sub-categories of rural households using firewood, which is firewood bought and firewood collected. In the case of firewood bought, the data is recorded in units of kilograms which are used by households. To convert firewood bought from kilograms into kilowatt hours, we multiplied total firewood bought (in kilograms) by a household in a month by 4.5kwh/kg, which is standard energy value per kilogram of firewood, according to Sustainable Energy Development Office, Government of Western Australia.

Firewood collected

In the case of firewood collected, we made several assumptions to get precise quantities of firewood collected by a single household, which are as following:

1. As in most cases, firewood is collected by foot, and by women and children, we assumed a standard weight of 5 kilograms each time firewood is collected. During the fieldwork, a standard of 5 kilograms was precisely confirmed by many households in different villages of different districts. For instance, if a household collects firewood by foot with the involvement of 2 household members three times a week, then the monthly weight of firewood collected is equal to [{(5 (kgs) x 2 (members)) x 3(times per week)} x 4(weeks per month)] or 120 kilograms of firewood collected.

2. As rural household specifically reported the limited availability of firewood for collection, we made the assumption of 5 kilograms constant, regardless of the means of transport used. This is only done for households which are collecting firewood on daily, weekly and monthly basis. However in the case of household collecting firewood quarterly, semi-annually, and annually and using tractors as a means of transport, we specifically asked the rough estimate for weight of collected firewood. Those households collect thick branches[8] of trees and reported around 2000- 3000 kilograms of firewood collected and then transported from their lands to their places.

Animal waste conversions

With livestock ownership

In EPS, rural households were asked the number of cattle they own. To avoid confusion with other animals in the category ‘cattle’, we specifically asked household for number of cows and buffalos they owned. This is due to the fact that rural households only utilize animal waste of these cattle as an energy source, making all of the remaining irrelevant for our analysis.

[8] In the case where household have their lands and are having trees which can be source for firewood collection, there is a sharp decrease in collection frequency of firewood. From such households, we also learned that they avoid deforestation of their lands as much as possible, so that they can get free wood from their lands periodically. In such cases, those households use branches from trees on their land and repeat the same process after fixed or variable interval.

Once livestock ownership is known, we made the following assumptions based on the information available from the field:

1. Amount of dung produced by an animal varies from 25 to 35 pounds depending on its size, age, health and availability of food. We took the average dung produced by animal as 30 pounds per day which is equivalent to 13.6 kilograms.

2. Once the total dung produced by all animals owned by a household is calculated, we assumed that half of it becomes manure for the field. From our field experiences, this might be equally true for households with and without land ownership. This is due to the fact that rural households have strong social interactions with each other, especially those with and without land ownership. Those without land ownership, in many cases, use their animal dung as manure in fields of their landlords, where they work, in a hope to get better harvest and consequently better share from the crops. Specifically, with the sharp rise of prices of fertilizers in Pakistan, a large proportion of our sampled households reported that animal waste is used as manure in the field, to save fertilizer expense.

3. Next step is to calculate the amount of animal waste that is dried and later used as an energy source. According to local veterinary experts, around 40-50% of animal waste contains water content, which gets evaporated during the drying process. To be precise as much as possible, we took 45% as average water content, and deducted it from the remaining 50% of animal dung left to be used as an energy source by rural households.

Mathematical Illustration

1 animal = 30 pounds of animal waste per day, also equals to 13.6kgs
50% used as manure = 6.8 kgs
50% used as an energy source= 6.8 kgs
Energy Source produced by drying process = 6.8 kgs – 45% of 6.8 kgs
Dried animal dung available as an energy source = 3.74 kgs per day per animal
Dried animal dung available as an energy source = 112.2 kgs per month per animal

Without livestock ownership[9]

In our dataset, households not having livestock and still using animal waste reported that they either buy or get it free of cost from neighbours who own livestock. This is a common practice in rural communities of Punjab. In such cases, households get them in the form of dried waste, available in the form of dried plates, each approximately weighing 120 grams. To get the total weight of animal waste used by a household, we multiplied 120 by number of dried dung plates and the divide it by 1000 for kilogram conversions.

To be precise in our calculations, we tried to investigate the different size and weights of animal plates available in different districts. We found that three different types based on their weights, i.e., 80 grams, 105 grams and 205 grams. The most common size available in most districts of Punjab was 105 grams. However in our calculations for animal dung usage by household, we took the average of three types and based our calculations on 130 grams per animal dung plate.

As in our data set, we have information on the rate per 100 animal dung plates, we can calculate the price for each animal dung plate. To get the number of animal dung plates used by

[9] Due to data unavailability for households without livestock ownership and still collecting animal waste from their neighbourhood, we have to drop 66 cases out of 404 cases using animal waste.

a single household per month, we then divided the monthly animal waste expenses by price of each animal dung plate. To convert the number of animal dung plates into kilograms, we multiplied the average weight of animal dung plate, which is 130 grams, by number of animal dung plates.

According to Texas Agricultural Experiment Station and Texas Cooperative Extension, the heating value of dried animal waste is estimated to be 8500 Btu/lb, which is equivalent to 18700 Btu/kg. To compare the energy value of animal waste with energy unit of electricity (kwh), a constant of 5.480 kwh is used instead of 18700 Btu/kg. By multiplying the total weight of animal waste used by a household by 5.480, we get the total energy value of animal waste in kilowatt hours.

Mathematical Illustration

Rate of dry animal dung plates = Rs. 100/100 plates
Price of single animal dung plate = 100/100 = Re. 1
Monthly expenses = Rs. 360
Number of animal dung plates used per month = 360
Average weight of dried animal dung plate = 130 gram
Total weight of animal dung plate = 130 x 360 = 46800 grams
Conversion of weight into kilograms = 46800/1000 = 46.8 kgs
Energy value per kilogram = 5.480 kwh
Total energy value per household for animal dung = 46.8 x 5.480 = 256.464 kwh

Plant waste conversions

For household using plant wastes collected from their field, assumptions are made similar to firewood collection. Refer to assumptions 1, 2 and 3.

Kerosene conversions

In the case of households using kerosene, we took the price of kerosene per litre reported by households and their monthly kerosene expenditures to calculate total quantity of kerosene used by a household in one month. To get the energy value per household for kerosene, we multiplied monthly quantity of kerosene by 11.97, which is amount of energy in kwh/litre of kerosene.

Liquid Petroleum Gas conversions

Similarly in the case of liquid petroleum gas, the monthly quantity of liquid petroleum gas reported by a single household is multiplied by standard energy value of 12.80 kwh/kg of liquid petroleum gas. This gives the total energy value of liquid petroleum gas per household.

Annex 2. : Descriptive Statistics for each indicator in each energy source

Table 15: Descriptive Statistics for Firewood (bought)

	Minimum	*Maximum*	*Mean*	*Std. Deviation*
Buying Frequency	3.00	10.00	7.9271	1.05017
Distance to Buy Firewood	1.00	5.00	2.5610	1.00541
Means of transportation	1.00	7.00	5.5977	1.89063
Household Involvement	1.00	4.00	1.0641	.31802
Time Spent per week (controlled)	0.033	45.000	1.7208	.6419318
Household Health	0	1	.53	.500
Children Involvement	0	2	.1731	.47321

Table 16: Descriptive Statistics for Firewood (collected)

	Minimum	*Maximum*	*Mean*	*Std. Deviation*
Collection Frequency	1.00	10.00	6.3185	2.28019
Distance to Collect Firewood	1.00	5.00	2.3370	1.18906
Means of transportation	1.00	7.00	6.0926	1.91325
Household Involvement	1.00	4.00	1.3963	.72295
Time Spent per week (controlled)	0.033	48.00	6.5691	1.0287273
Household Health	0	1	.53	.500
Children Involvement	0	2	.1731	.47321

Table 17: Descriptive Statistics for Animal Waste

	Minimum	*Maximum*	*Mean*	*Std. Deviation*
Collection Frequency	4	10	7.98	2.224
Distance to Collect Animal Waste	1	5	1.38	.681
Means of transportation	2	7	6.89	.688
Household Involvement	1	4	1.23	.561
Time Spent per week (controlled)	0.075	70.00	8.11442	1.5901772
Household Health	0	1	.43	.496
Children Involvement	0	2	.09	.334

Table 18: Descriptive Statistics for Plant waste

	Minimum	*Maximum*	*Mean*	*Std. Deviation*
Distance of Plant wastes (Buy)	1	5	2.40	1.100
Collection Frequency	2	10	5.21	1.360
Means of transportation	1	7	4.85	2.491
Household Involvement	1.00	4.00	1.3963	.72295
Time Spent per week (controlled)	0.125	49.00	5.99884	1.1864257
Household health	0	1	.46	.501
Children Involvement	0	2	.38	.684

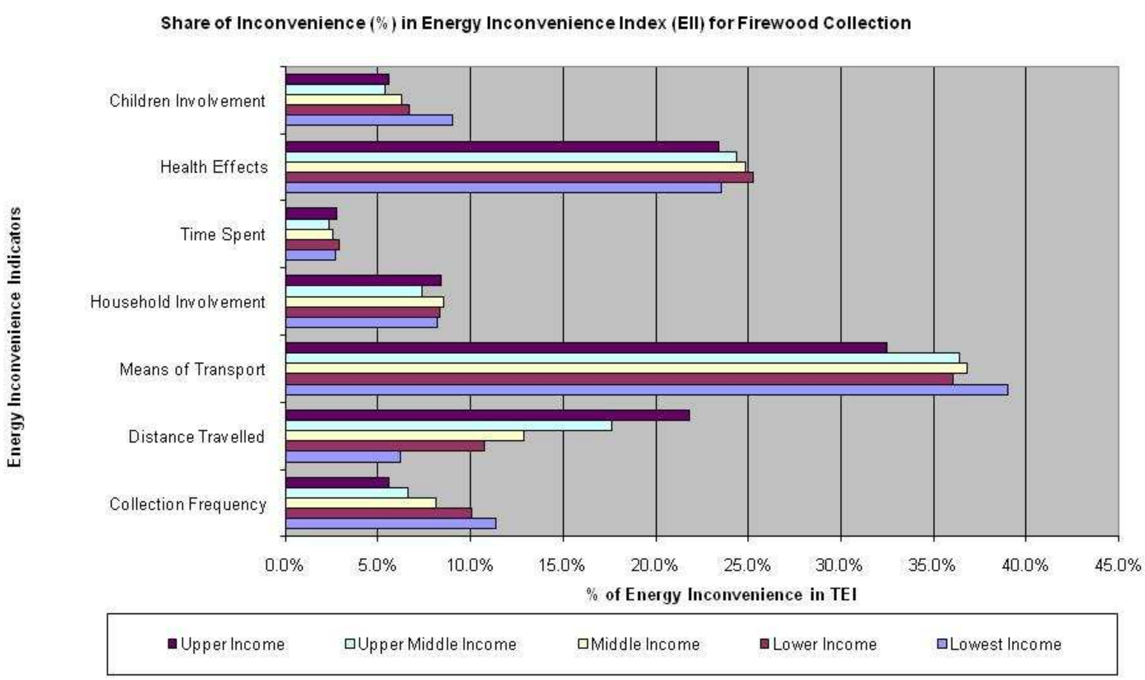
Table 19: Descriptive Statistics for Kerosene

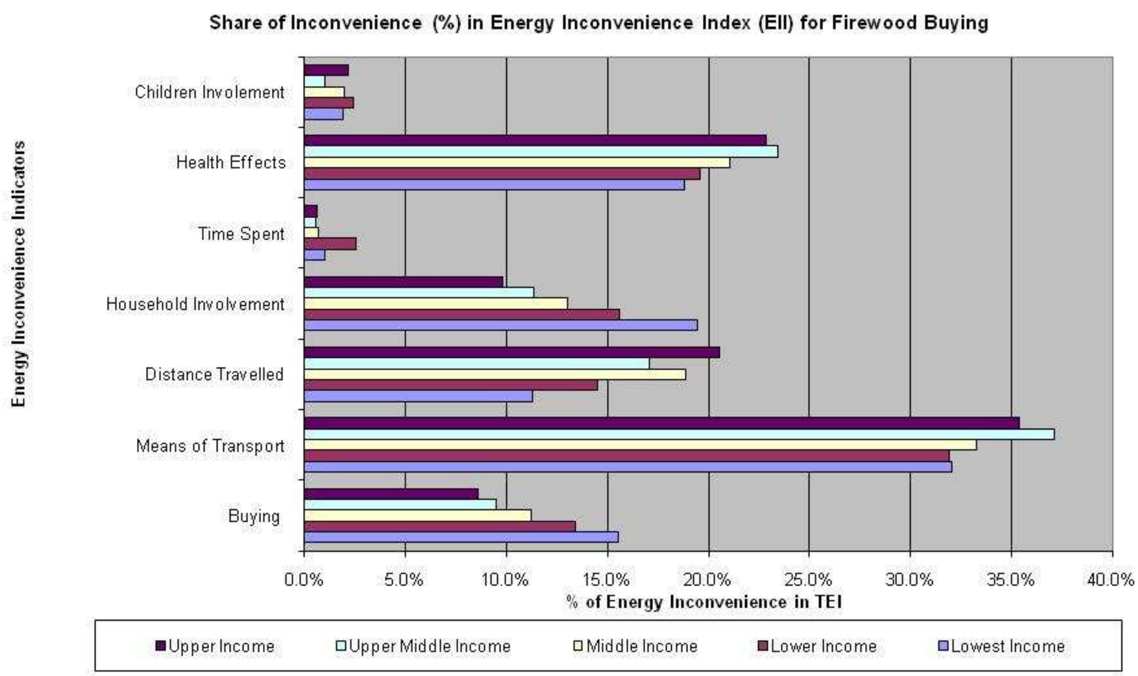
	Minimum	*Maximum*	*Mean*	*Std. Deviation*
Distance to travel for Kerosene	1	5	3.19	1.622
Means of transportation	1	7	5.65	1.811
Household Involvement	1	3	1.02	.154
Time Spent per week (controlled)	.020	30.00	2.61	.708
Household Health	0	1	.19	.391
Children Involvement	0	2	.24	.481

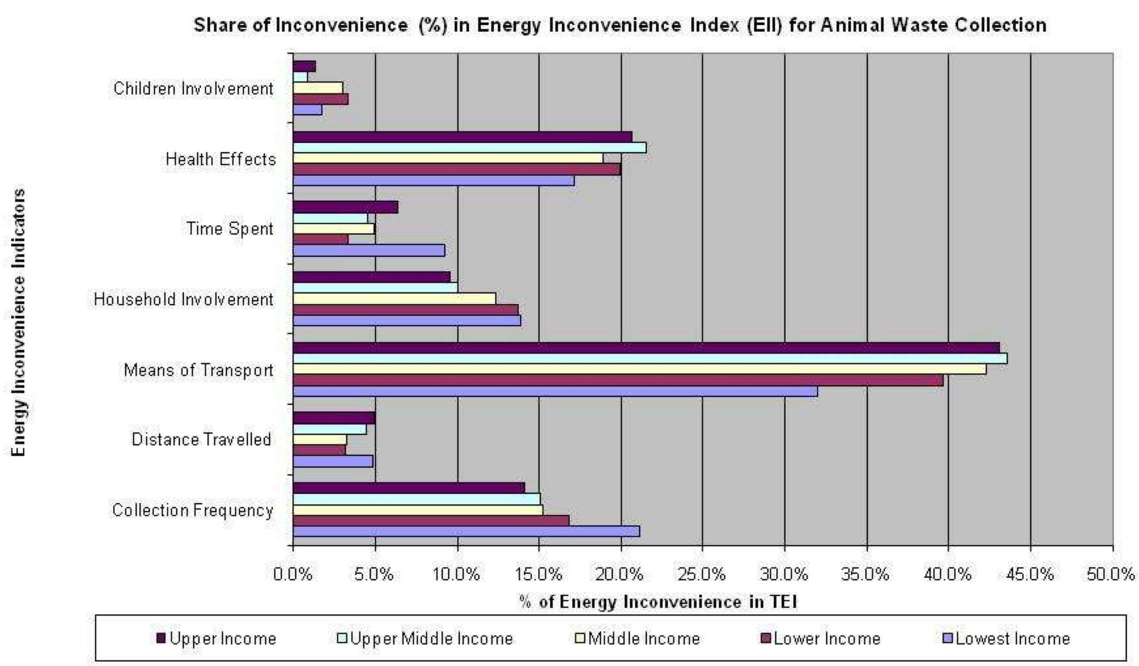
Table 20: Descriptive Statistics for Liquid Petroleum Gas (LPG)

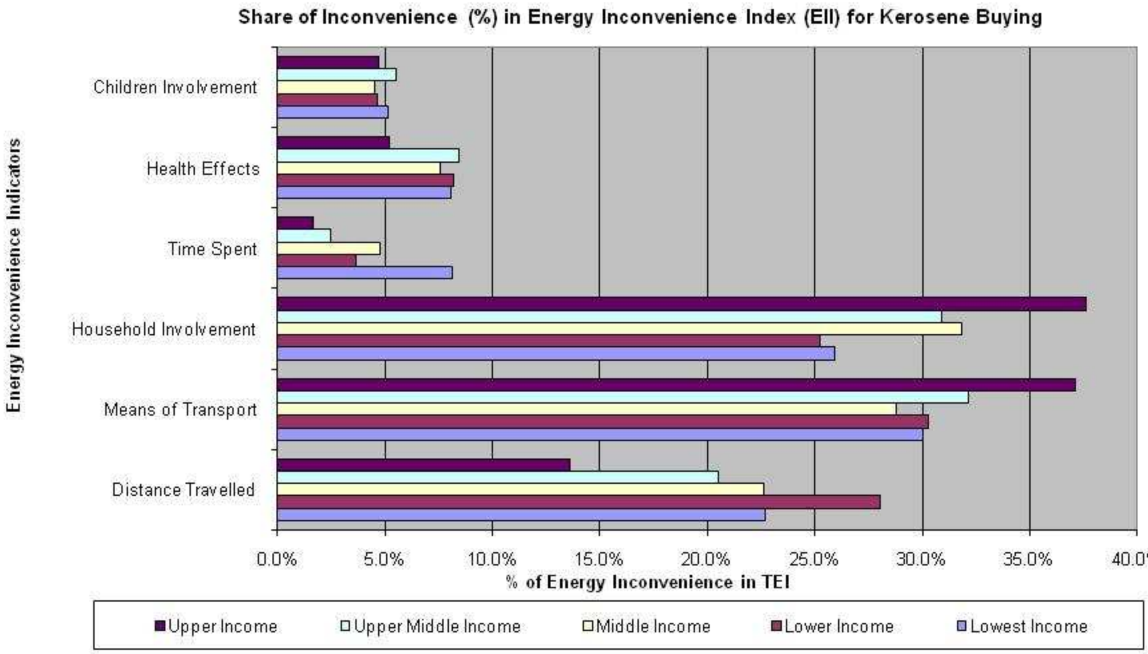
	Minimum	*Maximum*	*Mean*	*Std. Deviation*
Distance to travel for LPG	1	5	3.27	1.149
Means of transportation	1	7	5.39	1.486
Household Involvement	1	2	1.02	.138
Time Spent per week (controlled)	.041	4.00	.720	.0826
Children involved	0	1	.01	.121

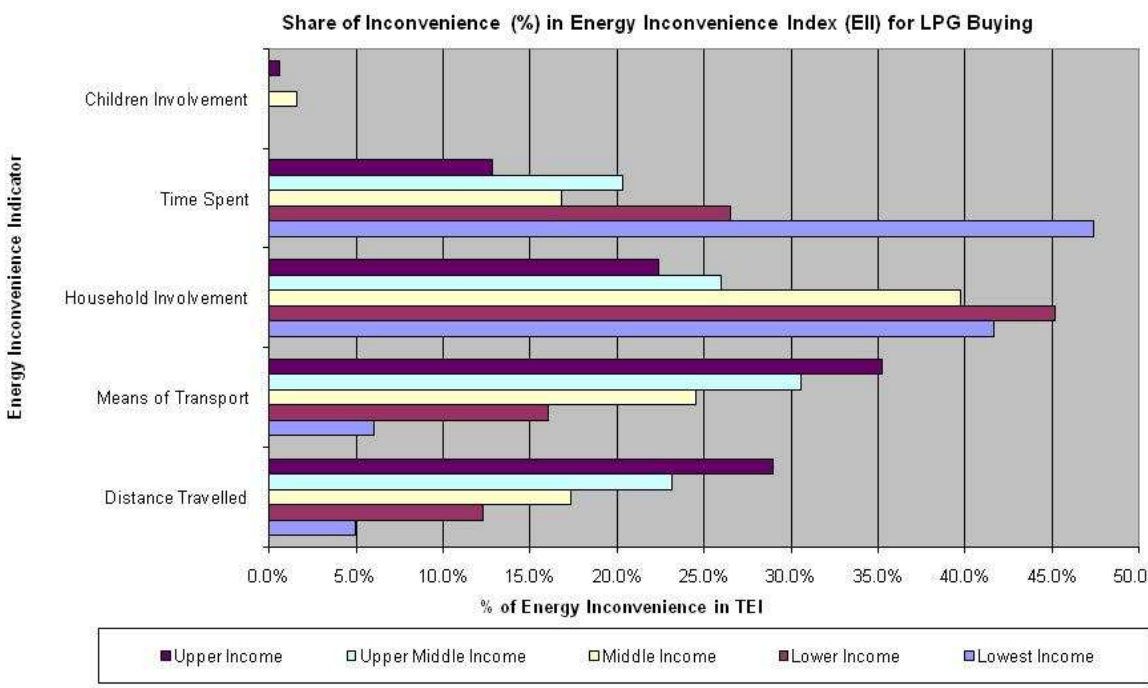
Annex 3: Bar Chart Representation of Data in Table 10




Share of Inconvenience (%) in Energy Inconvenience Index (EII) for Firewood Buying
Energy Inconvenience Indicators
Children Involement
Health Effects
Time Spent
Household Involvement
Distance Travelled
Means of Transport
Buying
0.0%
5.0%
10.0%
15.0%
20.0%
25.0%
30.0%
35.0%
40.0%
% of Energy Inconvenience in TEI
Upper Income
Upper Middle Income
Middle Income
Lower Income
Lowest Income


Share of Inconvenience (%) in Energy Inconvenience Index (EII) for Animal Waste Collection
Energy Inconvenience Indicators
Children Involvement
Health Effects
Time Spent
Household Involvement
Means of Transport
Distance Travelled
Collection Frequency
0.0%
5.0%
10.0%
15.0%
20.0%
25.0%
30.0%
35.0%
40.0%
45.0%
50.0%
% of Energy Inconvenience in TEI
Upper Income
Upper Middle Income
Middle Income
Lower Income
Lowest Income


Share of Inconvenience (%) in Energy Inconvenience Index (EII) for Kerosene Buying
Energy Inconvenience Indicators
Children Involvement
Health Effects
Time Spent
Household Involvement
Means of Transport
Distance Travelled
0.0% 5.0% 10.0% 15.0% 20.0% 25.0% 30.0% 35.0% 40.0%
% of Energy Inconvenience in TEI
Upper Income
Upper Middle Income
Middle Income
Lower Income
Lowest Income


Share of Inconvenience (%) in Energy Inconvenience Index (EII) for LPG Buying
Energy Inconvenience Indicator
Children Involvement
Time Spent
Household Involvement
Means of Transport
Distance Travelled
0.0% 5.0% 10.0% 15.0% 20.0% 25.0% 30.0% 35.0% 40.0% 45.0% 50.0%
% of Energy Inconvenience in TEI
Upper Income
Upper Middle Income
Middle Income
Lower Income
Lowest Income

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